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THE RESISTANCE OF HOLLOW GLASS MODELS TO UNDERWATER EXPLOSIONS AT GREAT DEPTHS III. SPHERES WITH OVERLAYS

17 MAY 1966

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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THE RESISTANCE OF HOLLOW GLASS MODELS TO UNDERWATER EXPLOSIONS AT GREAT DEPTHS III. SPHERES WITH OVERLAYS

by

Thomas B. Heathcote

ABSTRACT: Hollow glass spheres, 10 inches in diameter, were exposed to implosions of nearby spheres at 7,000, 10,000, and 21,000 ft depths in the ocean. Coatings of butyl and neoprene rubber, and syntactic foam increased the damage resistance at depth slightly; no significant differences among the three coatings nor between 1/2-inch and 1-inch thicknesses were found. Limited data indicate that resistance to implosions increases with depth.

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WHITE OAK, SILVER SPRING, MARYLAND

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The work described in this report is part of the U. S. Naval Ordnance Laboratory's program of development of glass submersibles. This investigation was carried out in FY 1966 under Task NOL-889/SP, and was funded by the Special Projects Office.

Mention of commercially available materials in this report does not constitute an endorsement or critism by the Laboratory.

J. A. DARE
Captain, USN
Commander

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By direction

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THE RESISTANCE OF HOLLOW GLASS MODELS TO UNDERWATER EXPLOSIONS AT GREAT DEPTHS III. SPHERES WITH OVERLAYS

1. INTRODUCTION

Results from sea tests conducted in March 1964 (a)* confirmed the hypothesis that hollow glass spheres became more resistant to damage as the hydrostatic pressure was increased. Additional tests conducted in June 1964 (b) showed that models covered with a layer of rubber or plastic were more resistant to damage than bare models. One-lb pentolite charges were used in these tests to produce the damaging energy.

Submersible structures have been proposed (c) which would have several glass spheres as buoyant members; these would be covered by coatings as an additional protection. Accidental implosion of one sphere might trigger the collapse of others and cause the loss of the entire array. It was of great practical interest to see whether this process became increasingly dangerous with depth.

In October 1965 tests were conducted at sea in an attempt to answer these questions. In order to reproduce the practical situation more closely, nearly all of the spheres were covered with protective coatings. This report presents the results of those tests.

2. EXPERIMENTAL PROCEDURE

2.1 General Procedure. As in previous tests (a, b), an explosive source and sphere were fastened to a steel rig at a measured distance apart and allowed to slide down a vertical wire. At a predetermined depth, the explosive source was triggered by pressure. In this series, the source was a hollow glass sphere which was caused to implode.

If the implosion failed to damage the target sphere, the next shot was at a smaller distance; the distance was reduced until breakage occurred. At that point, shots were fired to define the critical range if possible.

Seventy-nine tests were done at three depths. Several coatings were used. Figure 1 shows the various test arrangements, and Table 1 the nominal conditions. All shots were fired from the USNS GILLISS (AGOR-4) in or near the Puerto Rico Trench.

* Such letters refer to the List of References on Page 10.

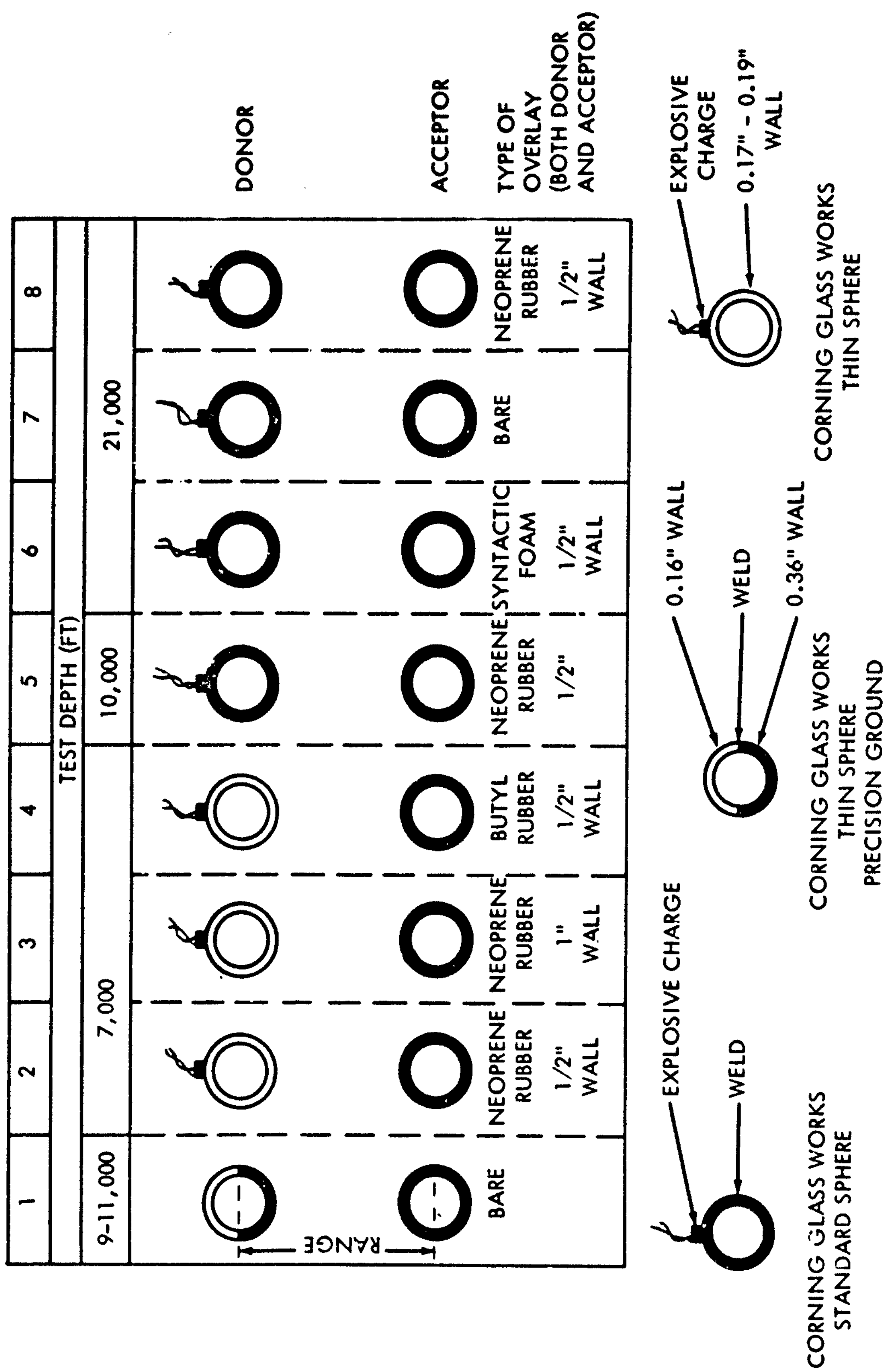

FIG. 1 TEST GEOMETRIES FOR DEEP SEA TESTS

TABLE 1

TEST CONDITIONS			
Test Depth (ft)	Approximate Water Depth (ft)	Number of Tests	Location
7,000	17,000	35	20° 58'N 67° 38'W
10,000	17,000	16	21° 00'N 67° 40'W
21,000	26,000	28	19° 36'N 68° 07'W

2.2 Test Rig. Figure 2 illustrates the type of test unit used in this series. Its construction was similar to the rig used in the previous sea tests (a) with the following exceptions: the length of steel pipe was halved and its weight per foot doubled, thus maintaining the previous free fall rate (~6.5 ft/sec) while increasing the ease of handling. The second modification was the replacement of the top charge holder by a model holder for the imploding sphere. A 6-gram Detasheet* charge was put in contact with the glass on the top side of the sphere; i.e., away from the acceptor sphere.

2.3 Glass Models. Three types of model fabricated by the Corning Glass Works, Corning, New York, were used in these tests. All were hollow spheres with 10 inch outside diameters, but with different wall thicknesses. As shown in Figure 1, all the acceptors were the Corning "standard sphere", with a 0.36 inch wall thickness, and identified as Corning Code 7740; fabrication details are outlined in reference (a). A new acceptor sphere was used on each test; if undamaged, the same spheres were then used as donors on test geometries 5 through 8. As also noted in Figure 1, Corning models with thin (0.17 to 0.19 in) walls were used as donors on tests 2, 3, and 4. The models used as donors on test geometry 1 were precision ground spheres made with two hemispheres of different thickness. The thinner hemisphere, calculated to implode at a known depth, was oriented away from the acceptor. On the tests, the spheres imploded at 10,000 ± 1000 feet.

2.4 Overlays. Most of the overlays used in these tests were made of neoprene rubber with a 1/2-inch wall thickness. A lesser number of neoprene overlays 1 inch thick, butyl rubber 1/2 inch thick, and 1/2 inch thick

* Manufactured by duPont de Nemours and Co.

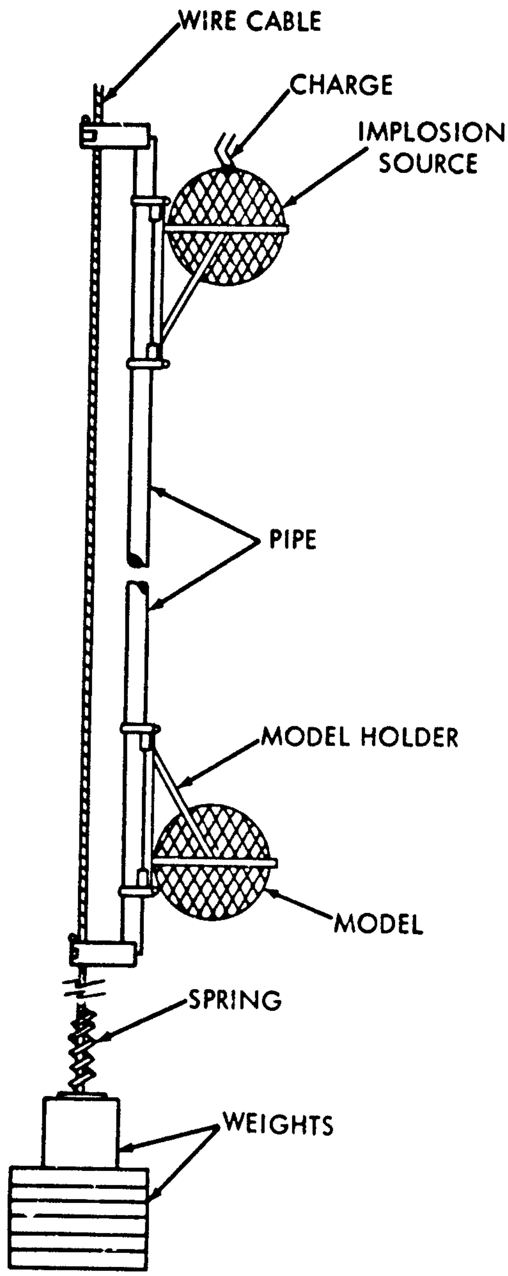

FIG.2 TEST RIG

syntactic foam* overlays were also used. All rubber overlays were fabricated in hemispherical form by the Non-magnetic Materials Division of this Laboratory. When being prepared for testing at sea, two identical hemispherical overlays were fitted to the glass model with their equators conforming to the equator of the spheres. A strip of Mystic tape was used to seal the joint where the two rubber hemispheres met and this seal proved to be very satisfactory in waterproofing the models, even at the deepest water depths. When positioned on the test unit (Figure 2) the poles of the donor and acceptor spheres faced each other.

Only a limited number of modified experiments were conducted using the syntactic foam overlays because of a defect in the overlay. While applying the overlays to the models prior to testing, it was found that the syntactic hemispheres were undersize so that a large gap existed between the two hemispheres along the equator of the model. Consequently, only one hemisphere was applied to each donor and each acceptor. These were oriented so that the poles of the syntactic hemispheres faced each other when positioned on the test unit. A new overlay was used for each test because of possible damage to the imbedded glass spheres.

2.5 Explosive. The explosive used on the clad donors throughout the series was a 1-foot length of Detasheet, EL-506C flexible explosive cord. The cord which contained 65 grains of PETN explosive was coiled in a flat circular pad and placed between the model and the overlay. The inside end of the coil of explosive was placed beneath a hole in the overlay located at a pole. The detonator of a pressure-actuated firing device was placed in the hole in contact with the explosive cord. The firing devices which worked on a rupture disc principle were purchased from Weston Instruments, Inc. and the detonators were provided by the Explosion Dynamics Division of NOL. The explosive load of the detonator was about 22.8 grains.

Essentially the same explosive arrangement was used on the unclad donor spheres; a small section of rubber was cut from the pole end of an expended overlay and placed over the pole of the bare model. This arrangement was made to provide a more positive contact of the detonator and explosive with the surface of the sphere. Once the explosive train was properly positioned, it was held rigidly in place by strands of tufting twine secured at four positions on top of the firing device and at four points on the model holder ring.

2.6 Procedure. For all tests, a 1000-lb weight was lowered on 1/2-inch diameter wire cable by means of an oceanographic winch to a depth 2000 ft beyond the nominal test depth. Then the test unit was clamped to the wire and allowed to slide down freely. When the test unit reached the predetermined depth, a detonator initiated by a pressure actuator fired the explosive; the unit continued to slide down the cable to the bottom end. The

* The "syntactic foam" material is a liquid epoxy resin in which are dispersed tiny hollow glass spheres. It is manufactured by Minnesota Mining and Mfg. Co. under the name of Scotchply Type XP-241-42.

number of test units dropped on each cable lowering ranged from five to eight.

The recording arrangements for this series were nearly identical to those illustrated in Figure 2 of reference (a). In general the sequence of events was as follows: Pressure pulses from the imploding spheres (d) were picked up by hydrophones lowered over the side to about 200 ft, and the signals fed to a tape recorder aboard the ship. The tapes were played back and the traces analyzed in an attempt to determine whether one or both spheres had been critically damaged. This method was not completely successful (see Appendix A) and consequently on most of the ensuing tests, the donor-to-acceptor stand-off was contingent on the damage incurred on the previous cable lowering. The extent of the damage was visually evaluated when a group of test units was brought to the surface. In most cases after an approximate break-no break range had been established, the distance between models was increased or decreased in 3-inch intervals within the limits of that range. The donor-to-acceptor stand-off was taken as the distance from the center of the donor sphere to the center of the acceptor sphere.

3. MODEL DAMAGE

The various types of damage that occurred to the acceptor spheres and any dissimilarities between the damage to bare and to clad models have been discussed in reference (b) and are as follows:

(a) The model was demolished. For the bare model the sphere was missing when the test unit was retrieved. For models with overlays, the pulverized or broken up glass was recovered inside the overlay.

(b) There was at least one hole in the model, usually at the pole away from the implosion. In most cases when an overlay was used, the hole occurred in both the overlay and the model. However, there were a few cases where the overlay was not completely destroyed and the models were dry inside.

(c) The model was cracked at the pole away from the implosion. The bare models usually had water inside, but the clad models were water-tight.

(d) A roughly circular section about 8 inches in diameter and half the model wall thickness deep was spalled from the outside of the model at the pole away from the donor. This damage occurred only on two clad models; the models contained no water when recovered.

(e) The internal bead around the equator joint flaked off. There was no leakage or evidence that cracks had propagated through the wall of the model on either clad or unclad models.

(f) No damage. The model was recovered intact.

A summary of the model damage is shown in Figure 3 for each condition as a function of the donor sphere to acceptor sphere range.

3.1 Damage Criteria for Test Results. Figure 3 shows clearly that the data are inadequate to define a single critical damage distance for each condition. As on previous tests (b), irregularities in the spheres and possibly in the coatings, probably account for the inconsistencies observed. In addition, the source of the implosion energy may not be reproducibly in the center of the sphere on every shot. Thus, the 3-inch distance increments were probably too fine for the small number of tests performed.

In lieu of a critical damage distance, two damage limits were established as follows:

(1) the upper limit was defined as the smallest distance where no damage other than flaking of the interior weld bead of the acceptor sphere occurred (no-break).

(2) the lower limit was taken as the greatest distance where the acceptor was demolished (break).

4. SUMMARY

A summary of the break and no-break distances as defined above for each type of sphere is given in Table 2. The spheres with 1-inch neoprene overlays are not included, since models were broken at all standoffs used.

In previous work (b), plastic or rubber overlays gave considerable protection at all depths tested. Here, at 21,000 ft, the 1/2-inch neoprene coated models are slightly more resistant to damage than the bare models. Data from the syntactic foam covered models is inadequate to distinguish these from either the coated or uncoated spheres. At 10,000 ft, the distance increments on the bare model tests are too great for clear definition of the damage distances; however, two spheres were demolished at a greater range than for collapse of any of the protected spheres. It seems clear that the coating has afforded some protection in these tests.

TABLE 2

SUMMARY OF MODEL DAMAGE RESULTS
Break and No-break Ranges (in feet)

Depth	7,000 ft		10,000 ft		21,000 ft	
	Break	No-Break	Break	No-Break	Break	No-Break
no overlay	--	--	(2.00)	(3.00)	1.50	1.75
1/2 in Neoprene	1.50	2.25	1.50	1.75	1.00	1.50
1/2 in Butyl	1.00	2.00	--	--	--	--
1/2 in Syntactic Foam	--	--	--	--	1.25	1.75

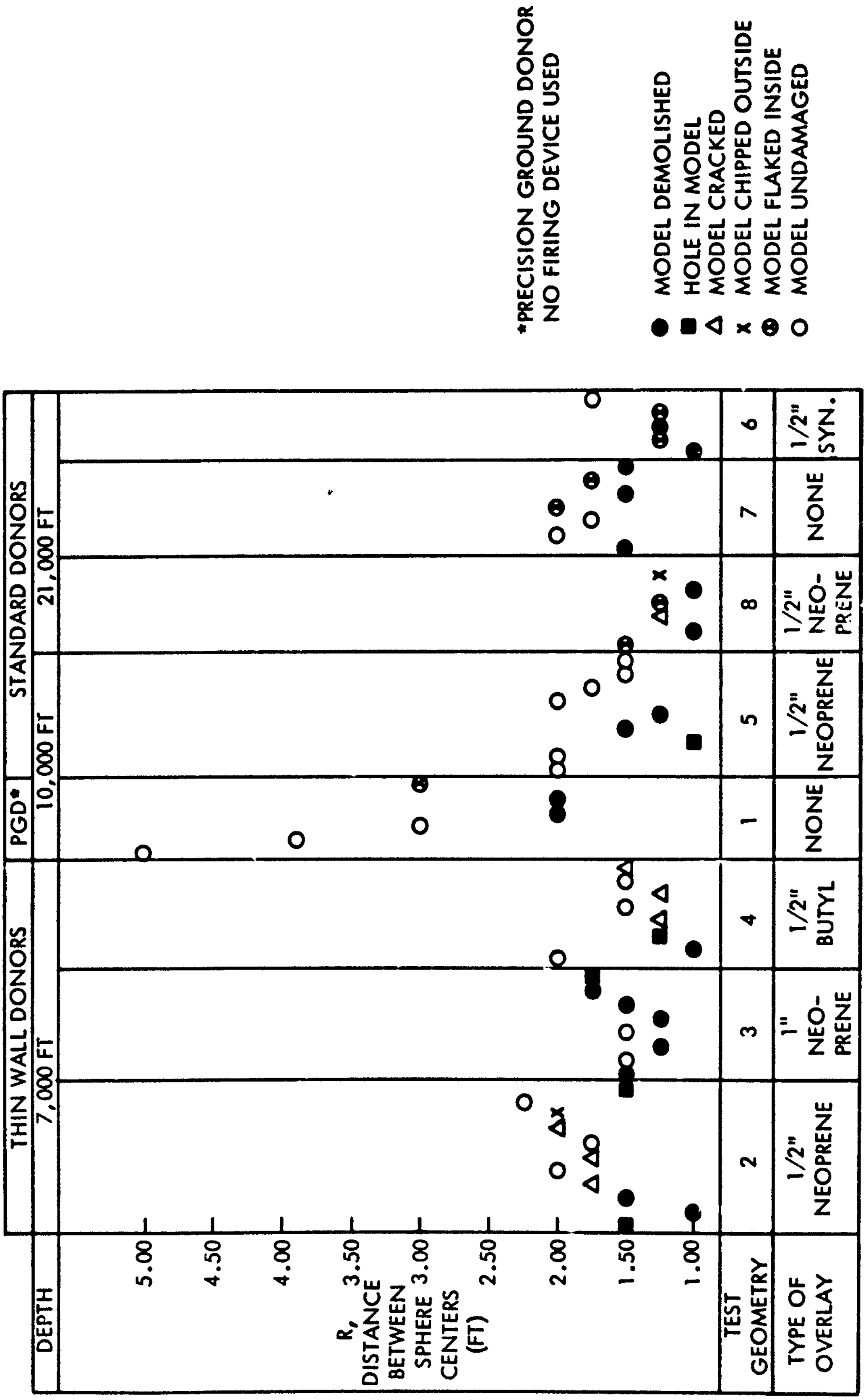

FIG.3 MODEL DAMAGE

The previous tests with overlays on the spheres (b) had indicated that the two materials used* offered essentially equal protection. Here, the 1/2-inch butyl rubber coating appeared to be slightly more effective than the neoprene coating at the 7000-ft depth, but the data are not conclusive.

In reference (a), it was shown that bare glass spheres become more resistant to explosion shock wave loading at great depths. In this study, it is evident that this effect is, as expected, also found when the spheres are covered with rubber and subjected to implosion generated shock waves. Thus, the results for the spheres coated with 1/2 inch of neoprene seem to show a decrease in the damage ranges with depth. However, there are insufficient data to determine this without qualification.

On these tests it was possible to determine from the pressure recording whether or not the acceptor sphere had been broken. However, it was not possible to differentiate between spheres that remained intact and those that were damaged to some degree less than collapse. Thus the recordings from a test could not be used to determine whether to increase or decrease the range in the next test, so it was necessary to recover and inspect the sphere before proceeding.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the helpful discussions and general guidance of W. H. Faux, H. A. Perry and C. R. Niffenegger. He also wishes to thank D. L. Marks, J. E. Morgan, E. G. Nacke and B. A. Robey, who carried out the field tests and B. E. Cox for his analytical studies of the test recordings.

* 1/2-inch butyl rubber on PPG spheres and 1/8-inch Peal Seal plastic on CGW spheres.

REFERENCES

(a) "The Resistance of Hollow Glass Models to Underwater Explosions at Great Depths. I. Spheres", W. H. Faux and C. R. Niffenegger, NOLTR 65-145, Dec 1965, Unclassified.

(b) "The Resistance of Hollow Glass Models to Underwater Explosions at Great Depths. II. Special Configurations", W. H. Faux, NOLTR 65-146, Jan 1966, Unclassified.

(c) "Feasibility of Transparent Hulls for Deep-Running Vehicles", H. A. Perry, ASME Paper, 63-WA-219, Nov 1963, Unclassified.

(d) "Implosions as Sources of Underwater Sound", R. J. Urick, U. S. Naval Ordnance Laboratory, White, Oak, Silver Spring, Md., reprinted from The Journal of the Acoustical Society of America, Vol. 35, No. 12, 2026-2027, Dec 1963, Unclassified.

APPENDIX A

PRESSURE PULSE MEASUREMENTS

A tape recorder and associated equipment were used to obtain pressure pulse signals from all tests. The main purposes were (a) to determine whether or not the donor and acceptor spheres imploded without retrieving the firing array after each test and (b) to obtain surface and bottom reflections for calculating the depths of implosions. It was also hoped that indications of intermediate degrees of damage could be found on the records.

A.1 Instrumentation. Three lead zirconate piezoelectric hydrophones, suspended 200 ft below the water surface, were used to receive the pressure pulses propagating from the implosions. The hydrophone signals were fed through 350 ft of low-noise coaxial cable, cable termination units, and pre-amplifiers into a four channel Model 411-C Lockheed tape recorder. A time signal was recorded simultaneously with the pressure signals. Voltage calibrations were recorded just prior to each test.

An LC-32* type hydrophone was used to receive the direct pressure pulses; these signals were fed into a direct recording channel. The frequency response of this channel was flat from about 100 cps to 20 kcs.

Two hydrophones, an LC-32 and an LC-50** were used to receive the surface and bottom reflections; these signals were fed into FM recording channels. The frequency response of these channels was flat from DC to about 2 kcs.

At sea, records were played out on a Model 903 Honeywell Visicorder. The direct pulses were played out at a paper speed of 50 cps. These were examined in an attempt to determine the level of damage to the acceptor sphere. After the conclusion of the sea tests, a more comprehensive study of the pressure pulse records was made from records played out on a Model 1612 Honeywell Visicorder. Paper speed for these records was 160 ips. Playouts for the calculation of firing depths and the water depth were made at a slower paper speed.*** A few of these records were made; calculations indicated that the nominal depths used (i.e., the depth settings of the hydrostatic devices) were accurate enough for these experiments (i.e., ± 5% of the nominal depth).

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* Manufactured by the Atlantic Research Corp.
** Manufactured by the Atlantic Research Corp.
*** "Studies of Explosions at Depths Greater than One Mile in the Ocean. III. Sonic Ranging of the Depth of Detonation", J. P. Slifko, NOLTM 10828, 15 March 1950, Unclassified.

A.2 Record Analysis. Figure A-1 shows typical records of the direct pulses obtained on the tests. The pulses are distorted somewhat because of the limited frequency response of the direct recording channel.

Figure A-1a is a record of a test on which the donor sphere was imploded by a small contact explosions; the acceptor sphere was undamaged. There were no signals on the records that could be identified as intermediate damage of the spheres, i.e., cracking at one pole, external chipping, or a small hole at one pole. If any signal was emitted by this type of damage, it was indistinguishable from the noise appearing on the records.

Table A-1 shows individual values of pressure for the explosion pulse (P_x), the donor implosions pulse (P_{x1}) and the implosion of the acceptor (P_{x2}). The data shown in Table A-1 are from a large selection of test conditions. Values are primarily intended for a qualitative rather than a quantitative presentation. However, the values for the donor spheres are shown in Figure A-2. It is apparent that the peak pressures from the bare spheres are considerably higher than those for the clad spheres. The pressures recorded for each type fall close to the normal pressure-distance decay curve, so it appears that there was no significant change in the peak pressure of the pulse as a function of depth of burst over the range of depths used. The pressure-time record is characterized by a small positive spike representing the explosion of the detonator and the EL506C explosive and a large positive pulse emitted when the air in imploded sphere has been compressed to its minimum. The negative phases after each pulse are probably a function of the poor low frequency response of the recording equipment rather than being pressure signals in the water. The pressure oscillations following the large pulse may be from oscillations of the air bubble.

Figure A-1b is similar to Figure A-1a except that the record is from a test on which the donor sphere was imploded by a small contact explosion; the acceptor sphere also broke. The wave shapes of the donor and acceptor implosions were nearly identical.

TABLE A-1

PRESSURES RECORDED AT 200 FOOT DEPTH

Test No.	Test Overlay	Model Standoff (ft)	P_x (psi)	P_{x1} (psi)	P_{x2} (psi)
Test Depth 7000 ft.					
21	1/2 in. Neoprene	1.00	0.138	0.329	0.488
18	" "	1.50	0.143	0.355	--
23	" "	1.50	0.123	0.304	--
28	" "	1.75	0.128	0.306	--
20	1 in. Neoprene	1.50	0.085	0.486	0.269
25	" "	1.50	0.136	0.333	--
53	" "	1.75	0.031	0.184	--
29	1/2 in. Butyl	1.00	0.193	0.414	0.148
34	" "	1.25	0.097	0.317	--
51	" "	1.25	0.070	0.377	--
24	" "	2.00	0.061	0.395	--
Test Depth 10,000 ft.					
4	Bare	3.00	None*	0.470	--
5	"	4.00	" *	0.514	--
7	"	5.00	" *	0.421	--
32	1/2 in. Neoprene	1.25	0.140	0.488	--
31	" "	1.50	NM	0.256	0.384
13	" "	2.00	0.045	0.212	--
Test Depth 14,000 ft.					
58	Bare	**	NM	0.258	--
89	"	**	NM	0.214	--
Test Depth 21,000 ft.					
69	Bare	1.50	NM	0.207	0.244
77	"	1.50	0.031	0.194	0.215
71	"	1.75	0.019	0.208	--
64	1/2 in. Neoprene	1.00	NM	0.129	0.205
65	" "	1.25	0.031	0.159	--
72	" "	1.25	0.028	0.156	--
62	" "	1.50	0.034	0.160	--

* No firing device used
** Only a standard donor model was used
NM Explosion pulse not measurable

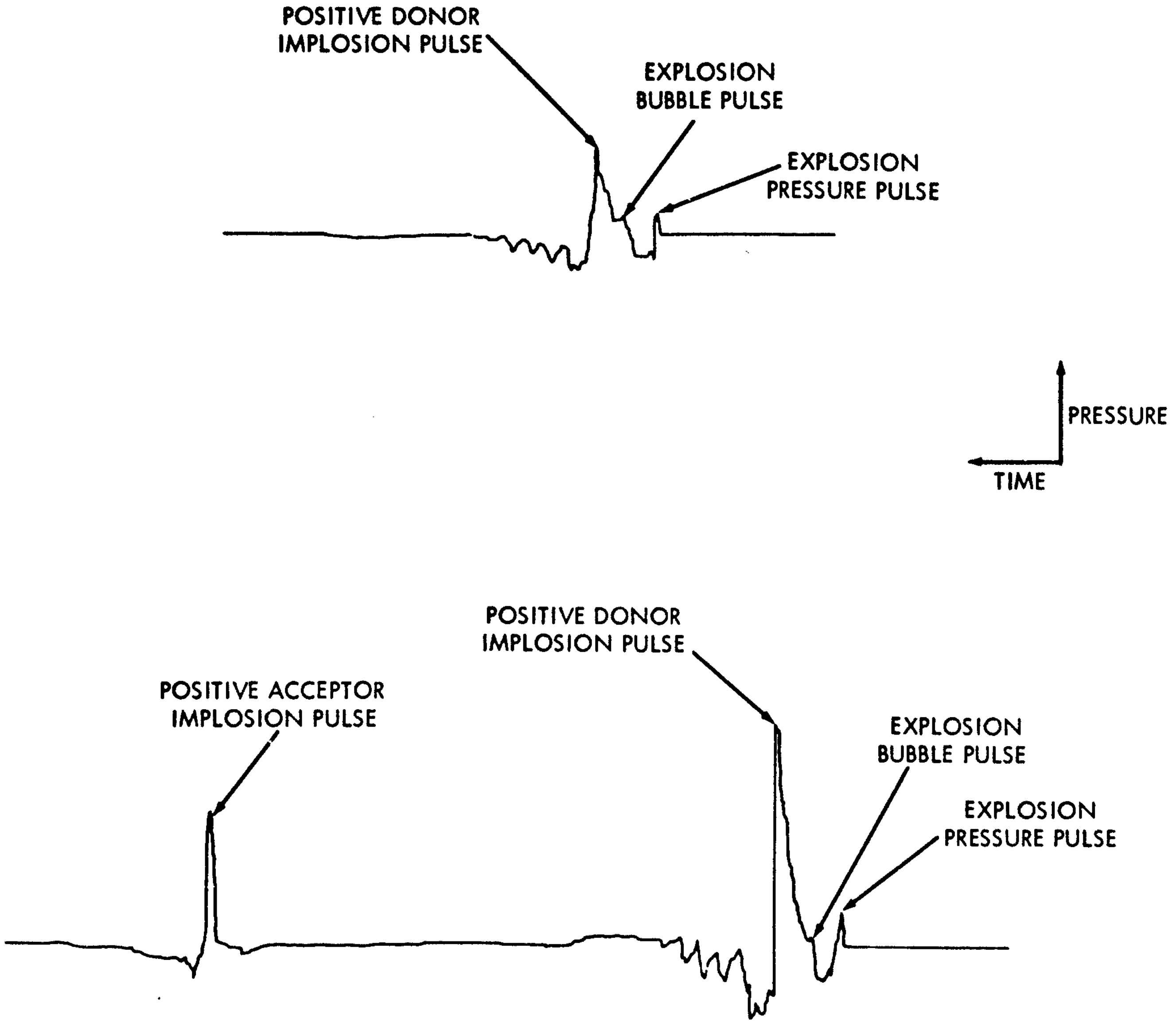

FIG.A-1 TYPICAL PRESSURE-TIME RECORDS

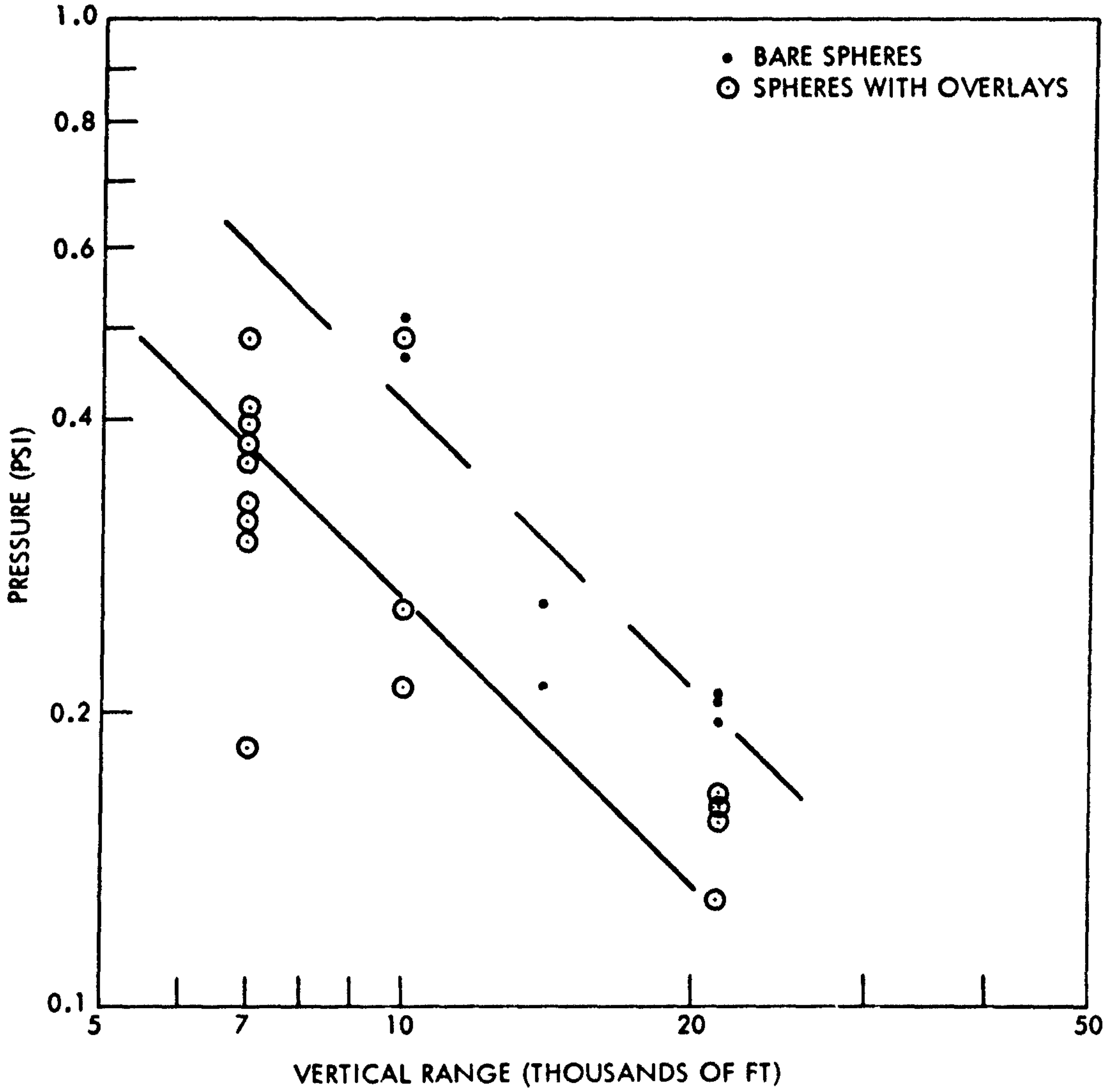

FIG.A-2 DONOR SPHERE PEAK PRESSURE

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13 ABSTRACT

Hollow glass spheres, 10 inches in diameter, were exposed to implosions of nearby spheres at 7,000, 10,000, and 21,000 ft depths in the ocean. Coatings of butyl and neoprene rubber, and syntactic foam increased the damage resistance at depth slightly; no significant differences among the three coatings nor between 1/2-inch and 1-inch thicknesses were found. Limited data indicate that resistance to implosions increases with depth.

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